

Microcomputer Control of an
Estuarine Research Mesocosm
Facility

Oregon State Univ., Newport

Prepared for

Corvallis Environmental Research Lab., OR

1986



U.S. Department of Commerce
National Technical Information Service

NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/J-86/408	2.	3. RECI PB88-104229
4. TITLE AND SUBTITLE Microcomputer control of an estuarine research mesocosm facility (Journal Version)	5. REPORT DATE 1986	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) B.E. Thomson and Robert C. Worrest	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hatfield Marine Science Center Oregon State University Newport, OR 97365	10. PROGRAM ELEMENT NO.	11. CONTRACT/GRANT NO. CR810288
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Corvallis, OR 97333	13. TYPE OF REPORT AND PERIOD COVERED Journal Article	14. SPONSORING AGENCY CODE EPA 600/02
15. SUPPLEMENTARY NOTES 1986. Journal of Microcomputer Applications 9, 167-177, July		
16. ABSTRACT This paper describes the application of microcomputer technology to laboratory-oriented ecosystem research. The instrumentation offers the ability to monitor and manipulate variables of interest on a 'real time' basis. The microcomputer control system was found to be reliable and accurate in controlling key environmental parameters.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
REPRODUCED BY U.S. DEPARTMENT OF COMMERCE NATIONAL TECHNICAL INFORMATION SERVICE SPRINGFIELD, VA 22161		
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 12
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

Journal of Microcomputer Applications (1986) 9, 167-177

Microcomputer control of an estuarine research mesocosm facility

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This paper describes the application of microcomputer technology to laboratory-orientated ecosystem research. The instrumentation offers the ability to monitor and manipulate variables of interest on a 'real time' basis. The microcomputer control system was found to be reliable and accurate in controlling key environmental parameters.

1. Introduction

In ecological research, a concept of great utility is that of the ecosystem. An ecosystem can be viewed as a complex of interactions between biotic and abiotic components such that the complexity of the whole system is greater than the sum of these elements. The study of ecosystems is a functional approach to understanding system parameters, such as exchange processes between components, as well as population parameters within components. In the marine environment, system parameters pertain to the interactions of various biological processes with physiochemical characteristics of the water column (e.g., nutrient cycling, turbulence, light attenuation). Population parameters pertain to aspects of the biological component such as photosynthesis, respiration, and community diversity (i.e., the number of different species composing the biological component). While the boundaries which delineate a marine ecosystem are debated among scientists, many would agree that the marine ecosystem is highly variable; not subject to manipulation for experimental purposes; and difficult to sample in anything less than an oceangoing vessel on a month-long cruise.

In an attempt to understand such a complex system, investigators study subsets of the larger natural system. These smaller, artificially bounded analogues to the real world are useful experimental tools in that they serve as living models of ecosystem processes (Pilson & Nixon, 1980). The attractive attributes of this microecosystem approach include replicability, which is amenable to statistical testing, and the ability to manipulate the system for experimental purposes. Models vary in size from small static benchtop enclosures to large enclosures designed to reflect natural fluctuations in the system being modeled. Recently, the term mesocosm has been suggested for enclosures exceeding benchtop capacity (Banse, 1982). If carefully designed for specific purposes, mesocosms can be validated as models of ecosystem processes (Leffler, 1980). The complexity of the design becomes a function of the number of biotic and abiotic variables the experimenter seeks to observe and manipulate.

In previous work, we made use of the microecosystem approach to examine the interaction of solar radiation with estuarine microorganisms (e.g., Worrest, Van Dyke & Thomson, 1978; Worrest, Thomson & Van Dyke, 1981; Thomson, Van Dyke &

Worrest, 1980). These studies utilized chambers ranging in size from static 5 l benchtop enclosures to 720 l chambers with seawater continuously flowing through them. In an attempt to have our investigations more closely approximate the natural system, we have sought to regulate key environmental variables on a 'real time' basis. The present report describes the design of our most recent effort in which we have used a microcomputer to monitor and control a mesocosm facility.

2. Design of the mesocosm facility

2.1 Overview

The estuarine research mesocosm (ERM) facility consists of twelve cylindrical fibreglass chambers (79 cm diameter $\times$ 72 cm water-depth, 350 l volume) housed in a 37 m² greenhouse (Figure 1) at the Hatfield Marine Science Center (HMSC) in Newport, Oregon. The long axis of the greenhouse has an east/west orientation. The HMSC is a 9300 m² marine research institution located 2 km from the ocean on Yaquina Bay estuary. Seawater from the estuary flows through the chambers at a rate which approximates the exchange rate or tidal flushing in the bay (Choi, 1975). This functions to flush the enclosures of metabolic by-products from the population of microorganisms grown in the mesocosms. In addition, it provides a fresh nutritive source to support continued growth. The rate of flushing is variable and can be modulated via electrically operated valves which are interfaced with the controller. The temperature of the water in the chambers is monitored and controlled by switching between two sources of estuarine water, one being ambient bay temperature and a second that is chilled to 5°C.

The ERM facility was specifically designed to investigate the effects of solar ultraviolet radiation in the 290–320 nm (UV-B) waveband on marine microorganisms. The greenhouse is glazed with a special low-iron-content glass (Sunadex, ASG Industries, Nashville, Tennessee) which filters out much of the solar UV-B radiation and transmits 95% of the solar spectrum above 360 nm (Figure 2). A combination of artificial sunlamps and glass filters (FS40 sunlamps and 1 mm thickness Schott WG320 filters) suspended above the chambers allow known quantities of UV-B radiation to be added

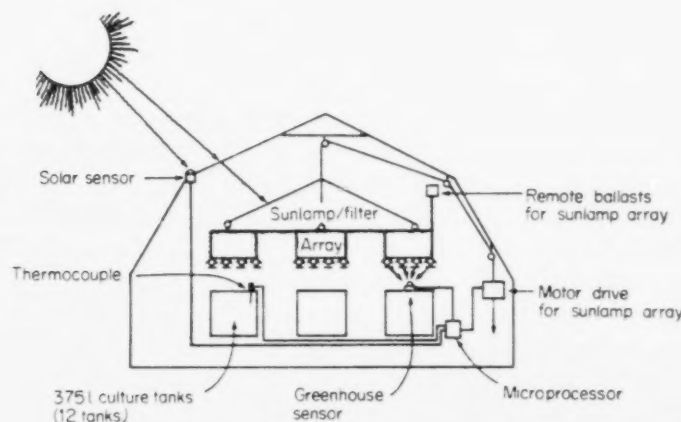


Figure 1. Diagram of mesocosm facility showing basic components of the overall design.

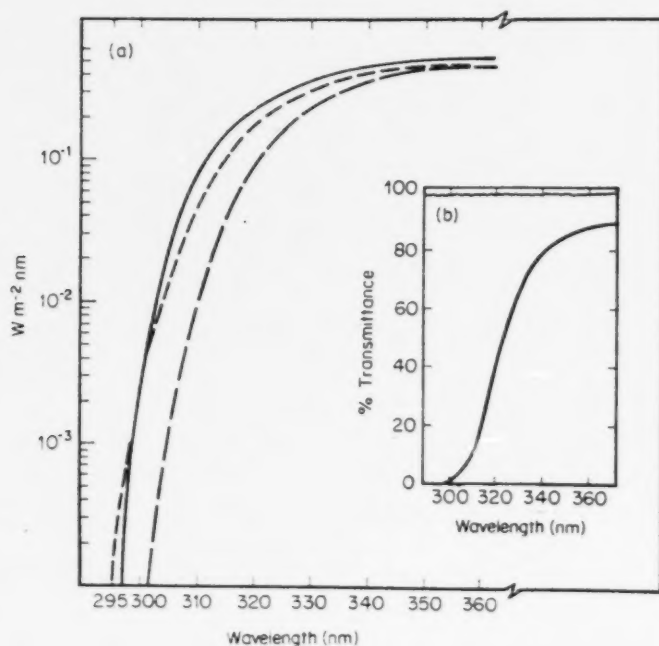


Figure 2. (a) Comparison among natural solar spectrum (—), solar spectrum inside the mesocosm facility (---), and the spectrum generated with sunlamp/filter array (-.-). (b) Transmission spectrum of greenhouse glass (Sunadex).

back into the spectrum. Ambient levels of incident solar UV-B radiation are monitored by the microcomputer system, which drives the sunlamp/filter array up and down based upon a comparison between an outdoor sensor and a sensor inside the greenhouse. The microcomputer turns the sunlamps on when natural levels reach a preset threshold and turns them off when the outdoor reading falls below the threshold. This typically occurs in the morning and evening, respectively; however, a similar sequence occurs whenever a cloud obscures the sun. In this way, the organisms in the mesocosms receive qualitatively and quantitatively the same spectrum with the inherent fluctuations that occur in the natural system. Through the use of neutral density filters, the dose of UV-B radiation can be altered. A comparison of mesocosms receiving different doses of radiation indicates the effect of UV-B radiation on the organisms.

2.2 System hardware

Control of the major environmental variables of the mesocosms is accomplished by an inexpensive, portable, and reliable system. A controller (Hewlett-Packard [HP] 41CV equipped with a 82182A Time Module) is interfaced with a data acquisition and control instrument (HP 3421A) and a printer (HP 82162A) for logging data (Figure 3). The data acquisition and control unit contains an eight-channel multiplexer assembly with a reference junction for thermocouple based temperature measurements. The multiplexer assembly is connected directly to a digital multimeter having a $1 \mu V$ sensitivity. This allows for transducer-based measurement of temperature of the mesocosms, solar UV-B irradiance outside of the greenhouse, and UV-B output of the sunlamp/filter array. In

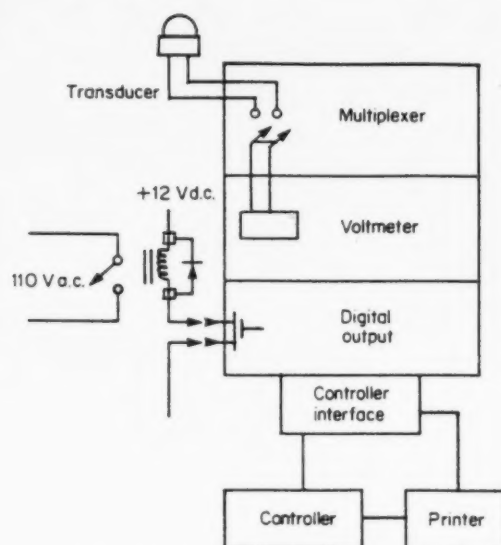


Figure 3. Schematic of the data acquisition and microcomputer control system.

addition, the HP 3421A contains an 8-bit output assembly which switches external 12 V d.c. solid-state optical relays. These relays control power to 110 V a.c. equipment such as fluorescent sunlamps, motor drive for sunlamp array, seawater valves for flow and temperature control, chemical feed pump for nutrient enrichment, and other equipment.

2.3 Software philosophy and detail

A modular approach to software development has been used to permit flexibility in adding the control of environmental variables to the system. The software is designed to use the HP 41CV as an automatic time-based controller. Figure 4 summarizes the main program and the temperature subroutine is outlined in Figure 5. During the evening hours, the program checks the temperature and then enters a 20 min delay. This delay is needed to prevent continuous alternating switching of seawater valves when the temperature is near the set point. During the daylight hours, the light routine functions as a delay period, thereby avoiding a similar switching effect.

Design criteria required the sunlamp array to mimic natural fluctuations in solar UV-B irradiance. Upon entering the sunlamps subroutine, the program takes a reading of the outdoor sensor. Once this reading exceeds a preset threshold, the lights are turned on. A series of ten readings are then taken during a time period which varies seasonally. This seasonal variation is a programmed part of the routine and ranges between 10 min (one reading per minute) and 30 min. When the comparison between the indoor reading and the average outdoor reading exceeds a preset tolerance, the lamps are moved up or down. The direction of movement is determined by the sign of the difference between the voltage at the indoor sensor and the average voltage at the outdoor sensor. The extent of movement of the sunlamp array is governed by a binary search procedure. The length of time that the motor is on is halved each time the motor comes 'on' in any given

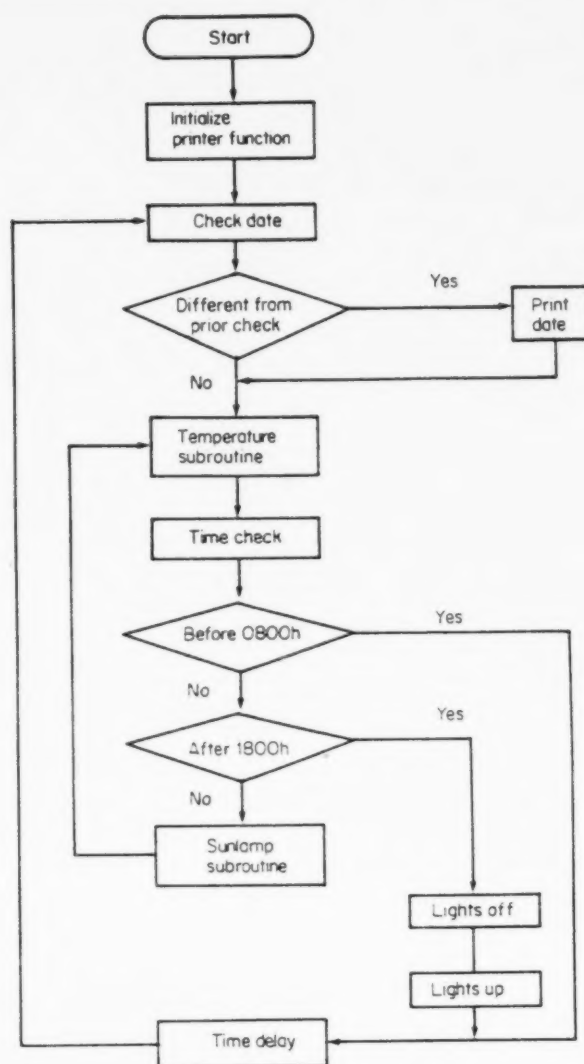


Figure 4. Overview of main program to monitor and control the major environmental variables of the mesocosms.

adjustment sequence (Figure 6). If this time is less than 0.1 s, then no adjustment occurs. Using this procedure, the lamps are adjusted to the correct distance above the tanks generally within three 'on' cycles of the motor. At the adjusted distance, the indoor sensor lies within 7% of the average voltage for the outdoor sensor. When a cloud obscures the sun such that the outdoor reading falls below the threshold, the lights are turned off, the sunlamp array is moved up, a counter is reset to zero, and another series of ten readings begins. If ten consecutive readings are below the threshold, then the sunlamps remain off and the routine returns to the main program at the level of the temperature subroutine.

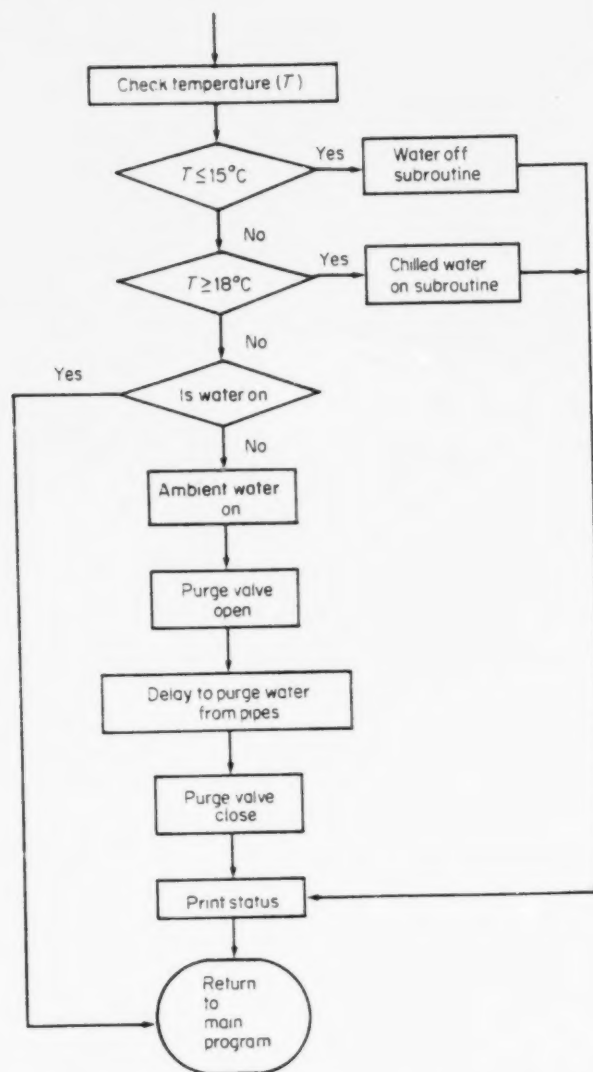


Figure 5. Temperature control routine. 'Chilled water on' and 'water off' subroutines are analogous to 'ambient water on' sequence.

3. Operational experience with microcomputer control of mesocosm facility

The use of the microcomputer system as a tool for controlling environmental variables was tested in the mesocosm facility. Population growth of *Thalassiosira weissflogii*, a centric planktonic marine diatom, was monitored for a period of ten days. Water column samples were withdrawn from the mesocosms at regular intervals during the test. Electronic particle counts and size frequency distributions were performed in triplicate on each sample using an Elzone 80XY Particle Counter (Particle Data, Inc., Elmhurst, Illinois, USA). Population parameters included cell concentration, as well as the mean,

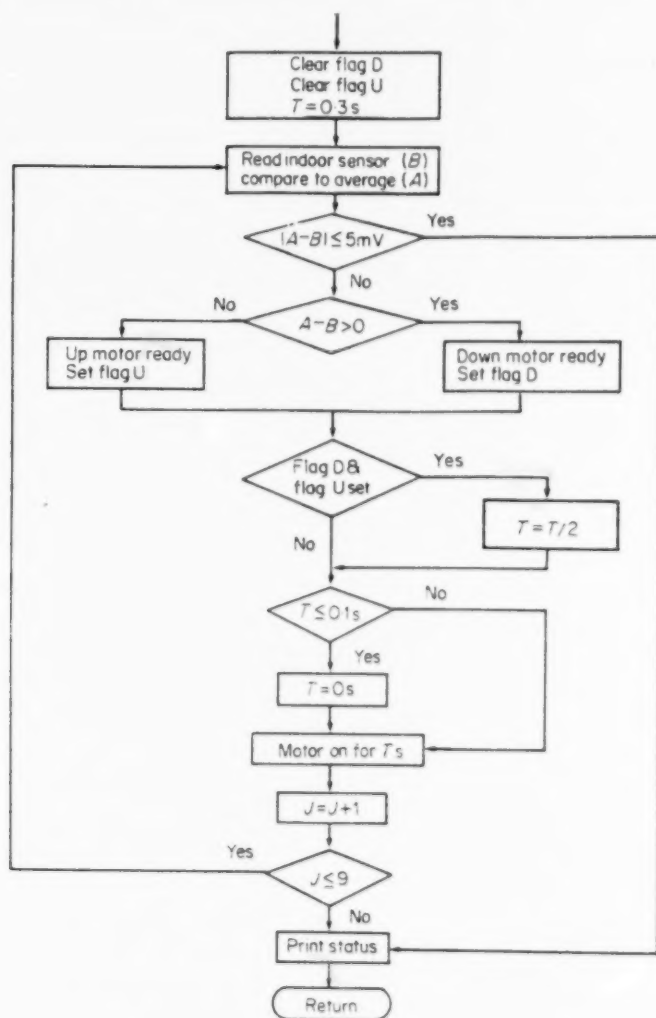


Figure 6. Binary search sequence within the routine for positioning of sunlamp/filter array.

median, and mode of the size distribution. No difference was found in the mean, median, or mode of the size distribution. A linear model was fitted to the population counts obtained over the ten-day period in each of the twelve tanks. The R^2 value of these twelve regressions ranged from 0.87 to 0.98. The slopes of the regression lines for the first ten days were compared using two-way analysis of variance. For this analysis the tanks were grouped according to their row and column position, corresponding to a north/south and east/west orientation. There was no significant position effect in the east/west plane; however, there was a significant position effect in the north/south orientation. Dropping the north row of tanks from the analysis resulted in there being no significant position effect in either plane (Table 1). The north row of tanks was excluded from further consideration and the remaining eight tanks were monitored for an additional twelve days. A linear model was fitted to the population counts in each of the

Table 1. Two-way classification, analysis of variance. *P*-values for slope of regression lines on population counts for: (a) 10-day period, 12 mesocosms; (b) 10-day period, eight mesocosms (two rows only); (c) subsequent 12-day period, eight mesocosms

	<i>P</i> -value		
	(a)	(b)	(c)
Row effect	0.0176	0.4503	0.4256
Column effect	0.1792	0.7937	0.7287

tanks for this 12-day period (Figure 7). Analysis of variance on the slopes of the regression shows the tanks to be not significantly different from each other (Table 1).

To test if UV-B radiation (290–320 nm) has a measurable effect on planktonic populations a second experiment was performed. The twelve mesocosms were inoculated with *Thalassiosira pseudonana* and were treated similarly for eleven days. Analysis of variance of the population counts indicated a significant position effect in the north/south plane. Dropping the north row from the analysis permitted the remaining eight tanks to be considered replicates. The remaining tanks were exposed to two levels

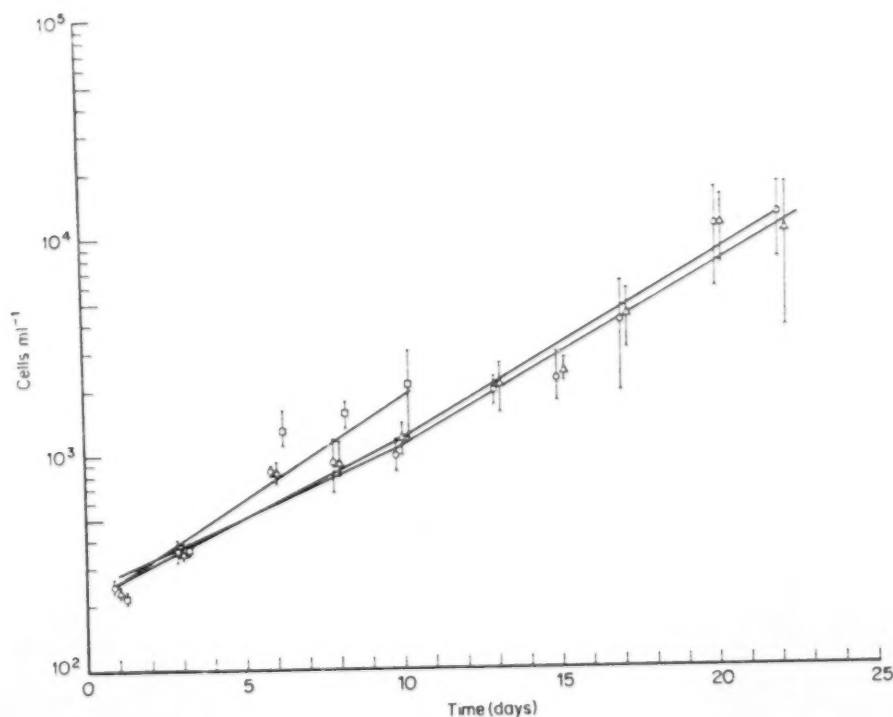


Figure 7. Least squares regression analysis of population means for *Thalassiosira weissflogii* grouped according to row location in mesocosm facility. Each mean is for four mesocosms; error bars represent one standard deviation. ○: south row; △: centre row; □: north row.

of UV-B radiation for seven days and the response of the populations was monitored. One level of UV exposure mimicked the ambient outdoor regime and the second exposure group was at an enhanced level. The populations in the tanks exposed to the enhanced level of UV-B radiation showed a significant decrease in numbers when compared to the mesocosms receiving the ambient exposure (Figure 8).

The four mesocosms in the north row of tanks appear to be aberrant when compared to the other eight mesocosms. The apparent explanation for this is an unevenness in the distribution of radiant energy inside the greenhouse. The angle of incidence of direct solar insolation on the sloping greenhouse roof appears to be the critical factor. The north row of tanks, because of their position with respect to the peak of the greenhouse roof, received different amounts of direct solar radiation than the other eight mesocosms. At this latitude the effect is maximal on clear days when direct radiation predominates over 'sky shine' and when the solar zenith angle is minimal, i.e., around summer solstice. The effect is minimal at other seasons or when persistent cloud cover results in 'sky shine' being the predominant source of insolation. Measurements and observations at different times of the year have documented this effect. Corrective measures to remedy this source of variation include relocation of the north row of tanks, reconstruction of the greenhouse with the long axis oriented in a north/south plane, or utilization of neutral density filters. Without these corrective steps the number of replicate mesocosms is reduced.

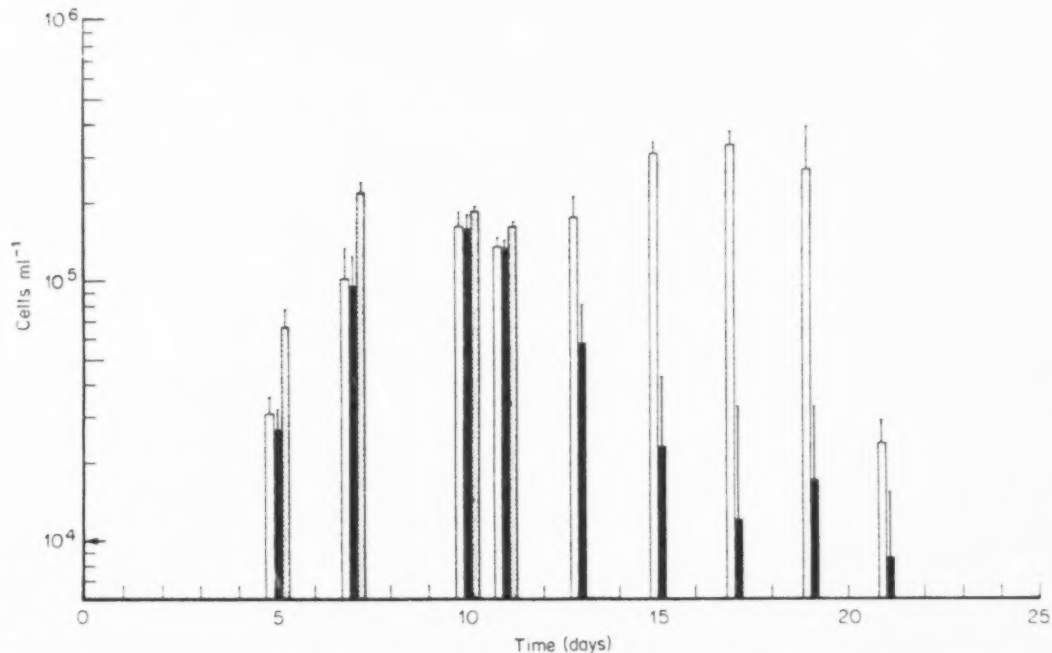


Figure 8. Population counts in mesocosms inoculated with *Thalassiosira pseudonana* during an experiment to test for effects of exposure to enhanced levels of UV-B radiation. Exposure began on day 12. Error bars represent one standard deviation. Arrow indicates population means at the beginning of the experiment. □: south row; ■: centre row; ▒: north row.

4. Conclusion

The instrumentation described in this paper was found to be reliable and accurate in monitoring and controlling key environmental variables on a 'real time' basis. Eight of the mesocosms were found to be replicates and can be used to test for treatment effects of UV-B radiation, or any other treatment, on estuarine microorganisms. The use of the microcomputer controller simplified the task of monitoring and controlling environmental variables of principal importance to our model system. Manipulation of variables for experimental purposes is expedited to the extent that an existing design can be altered through software changes. As conditions vary in the 'real world', program alternatives fine-tune the model to reflect these changes. Increased understanding of ecosystems may require that more variables be 'plugged into' model systems. By maximizing the properties common to both the model and the ecosystem being modeled, the validity of predictions based on the results are enhanced.

Acknowledgement

Appreciation is expressed to Craig Smith, Ted Wadman and Grapevine Publications for their technical assistance. Although the research described in this article has been funded in part by the United States Environmental Protection Agency through cooperative agreement CR810288 with Oregon State University, it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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